

# Random Surface Texturing of mc-Silicon for Solar Cells with Picosecond Lasers; a Comparison between 1064 nm, 532 nm and 355 nm Laser Emission Wavelengths

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**Abstract:** Multicrystalline Silicon was textured with picosecond laser. Different laser wavelengths ( $\lambda = 1064, 532, 355$  nm) were compared regarding laser-induced damage. We found that  $\lambda = 355$  nm picosecond radiation resulted in shallower defect-reach region

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## Introduction

Surface texturing plays a critical role on the performance of silicon solar cells, affecting both reflectance and light trapping. Surface texturing using femtosecond lasers by creation of self-organizing structures was demonstrated to effectively modify the surface morphology of silicon and consequently tailoring the optical properties of the processed samples [1]. Picosecond lasers, nowadays more attractive for the industry having higher power outputs, can in principle be exploited to achieve similar textures at a faster production rate. The aim of this work is to study the effect of picosecond laser radiation on the reflectance of mc-Si as well as the effect of different laser wavelengths during the manufacturing process on the generation of subsurface laser-induced defects.

## Experimental setup

A commercial Nd:YAG laser amplifier (Fuego® by Time-Bandwidth Products AG) was used to generate laser pulses of  $\sim 10$  ps. The central wavelength of 1064 nm (IR) was converted to 532 nm (Green) and 355 nm (UV) using a second and third harmonic generation box, respectively. Galvano-scanners, equipped with telecentric lenses (100 and 160 mm focal), were adopted to scan the laser beam over the surface of the samples.

## Experimental approach

The mc-Silicon test samples of  $39 \times 39$  cm<sup>2</sup> were produced by cutting pre-treated standard 6 inches wafers. The pre-treatment consisted of a light KOH etch to remove the saw cut damage. An empirical approach was adopted to find the processing parameters for creating surface texturing of the samples for each of the three laser wavelengths adopted. The obtained samples were then optically analyzed and three representative samples for the three different wavelengths were selected for further analysis.

## Experimental results and discussion

Optical properties: the reflectivity of the samples, measured with a spectrophotometer (AvaSpec® by Avantes) equipped with an integrating sphere, was found deeply modified upon laser texturing. The average reflectance in the 400-1000 nm range decreased from the original average value of about 27.5% to average 8.6%, 11.7%, 9.6% for the selected samples treated with IR, Green and UV, respectively. This shows the effectiveness of picosecond laser texturing on mc-Si.

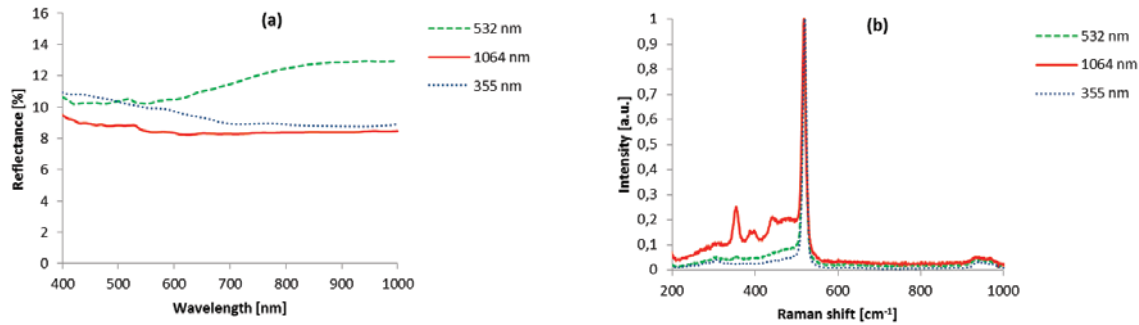


Fig 1 a) Spectral reflectivity of untreated and laser textured mc-Si at the three different wavelengths.

b) Confocal MicroRaman spectra of samples treated at  $\lambda = 1064$  nm, 532 nm, 355 nm.

MicroRaman analysis: the samples were analyzed using a MicroRaman spectrometer (Ventuno® by Jasco), in confocal configuration. The analysis shows the presence of an amorphous phase at lower Raman shift with respect to crystalline silicon, whose presence is induced by the laser treatment (fig. 1 (b)). The peak area of the detected amorphous Raman signal strongly decrease with laser wavelength shortening, indicating a higher damage in the case of the laser textured samples at  $\lambda = 532$  and 1064 nm, in the range of 1-1.5  $\mu\text{m}$  and  $> 2$   $\mu\text{m}$ , respectively. Moreover, preliminary confocal analyses suggested that the amorphous layer in UV laser textured samples shows a shallow localization, below 0.2  $\mu\text{m}$ , which possibly will not hinder the cells electrical performance.

Photoluminescence analysis: samples were analyzed by photoluminescence (PL) at room temperature (RT). Photoluminescence spectra were recorded with a spectral resolution of 6.6 nm, using a standard lock-in technique in conjunction with a single grating monochromator and an InGaAs detector. A quantum well laser ( $\lambda=805$  nm) was used as excitation source. The Si band- to-band related signal around 1150 nm clearly observed in the not textured zones is still detectable just in the case of the 355 nm laser textured sample (fig. 2 (a)). The absence of Si related emissions in the laser textured samples at  $\lambda = 532$  and 1064 nm is in agreement with the higher laser induced damage deduced from Raman results. A further emission around 1600 nm was observed in the 355 nm laser textured sample, which is probably related to extended defects like dislocations.

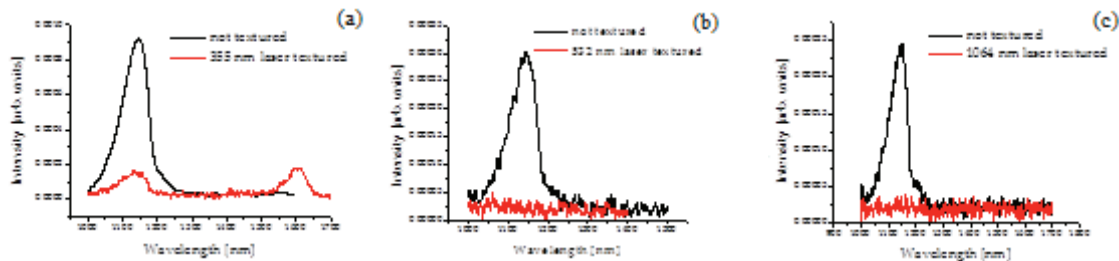


Fig 3: PL spectra at RT of samples treated at  $\lambda = 355$  (a), 532 (b), 1064 nm (c).

## Summary

Multicrystalline Silicon was textured with picosecond laser. Different laser wavelengths ( $\lambda = 1064, 532, 355$  nm) were compared regarding laser-induced damage. We found that  $\lambda = 355$  nm picosecond radiation resulted in shallower defect-reach region. We found optimal laser and optics parameters in order to obtain significant reduction, up to 70% in average in the 400-1000 nm wavelength range, of mc-Silicon reflectivity. This was achieved still maintaining, in case of 355 nm laser emission, good crystal quality. Investigation by confocal microRaman spectroscopy shows the decrease of depth of subsurface laser-induced defects when decreasing the emission wavelength. Photoluminescence spectra recorded at room temperature confirmed the results obtained by Raman, showing detectable emission in case of the laser treatment at  $\lambda = 355$  nm that is, on the contrary, completely absent in case of 532 nm and 1064 nm treatments.

[1] T.-H. Her, R.J. Finlay, C. Wu, S. Deliwala and E. Mazur, "Microstructuring of silicon with femtosecond laser pulses," Appl. Phys. Lett., 73, 1673-1675 (1998).